Additional HCl was added as required to maintain the solution acidity. After an appropriate time period, usually 1 h, the products were isolated by dilution with water followed by filtration or extraction with ether. Table I presents results for a variety of structural types. As evident, the method appears suitable for conjugated derivatives which are activated by a nitro group (entry 14) or by two α-positioned electron-withdrawing substituents including ester, cyano, lactone, ketone, or amide in varying combinations. Singly substituted double bonds as in ethyl cinnamate (entry 16) are resistant and aryl substitution enhances the reduction rate (entry 15). The method is quite selective in that other functional groups are unaffected including amido (entries 7, 10, 13), aromatic and aliphatic nitro (entries 4–6, 9, 14, 17) or cyano (entries 8–13) moieties, esters (entries 1–12, 15, 16), lactones (entries 17–19), or aryl ketones (entries 17–19). Furthermore, in contrast to analogous reductions with $NaBH_4$,[5d,e] cyano esters are not further reduced to the corresponding cyano alcohols. The use of acid, although not essential, results in higher yields (compare entries 1 and 3), ostensibly by rapid protonation of initially produced stable α carbanions before side reactions can intervene. This is evidenced by the relatively high yield of 1-methyl-2-phenylnitroethane obtained (entry 14) compared to previous investigations[7a,b] coupled with the absence of dimeric Michael products which are concomitantly produced with other hydride reagents.[7a,11]

Experimental Section

Materials. $NaBH_3CN$ was obtained from Aldrich Chemical Co. and used without purification. Starting materials were either obtained commercially or prepared by standard procedures.[12] All new compounds gave satisfactory elemental analysis and showed spectral (ir and NMR) data consistant with the structures. Elemental analyses were provided by Chemalytics, Inc., Tempe, Ariz., copies of which have been provided the Editor.

General Reduction Procedure. The general procedure utilized is presented in the text and is described below for the reduction of 6-nitro-3-benzoylcoumarin.

6-Nitro-3-benzoyl-3,4-dihydrocoumarin. A slurry of 6-nitro-3-benzoylcoumarin (2.95 g, 10 mmol), $NaBH_3CN$ (0.69 g, 11 mmol), and a small amount of bromocresol green indicator in 25 ml of ethanol was magnetically stirred while concentrated HCl was added dropwise until the color changed to yellow. Periodically, additional HCl was added in order to maintain the yellow color. After 1.5 h the reaction mixture was diluted with ca. 150 ml of water and cooled and the resulting while needles were filtered and dried under vacuum (2.54 g, 86%). The ir and NMR indicated complete reduction of the double bond.

Anal. Calcd for $C_{16}H_{11}NO_5$: C, 64.65; H, 3.73. Found: C, 64.70; H, 3.55.

Acknowledgment. The authors thank the donors of the Petroleum Research Fund, administrated by the American Chemical Society, for partial support of this work.

Registry No.—$NaBH_3CN$, 25895-60-7.

References and Notes

(1) Recent studies include the successful reduction of conjugated ketones to the corresponding saturated derivatives with potassium tri-*sec*-butylborohydride,[2a] various Cu(I) H complexes,[2b-e] hydrosilanerhodium(I) complexes,[2f] and ferrocene–HCl.[2g] Tetrahydroaluminate,[2h] borohydride,[3] and cyanoborohydride[4] are less discriminate and carbonyl reduction competes favorably in most cases.

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(11) The results further suggest the intriguing possibility of generating enolate ions in aprotic solvents with cyanoborohydrides which can subsequently be exploited for condensation or alkylation reactions.[9] This tactic is being actively pursued.

(12) (a) α,β-Unsaturated cyanoacetates: F. D. Popp, *J. Org. Chem.*, **25**, 646 (1960). (b) α,β-Unsaturated malonates: C. F. H. Allen and F. W. Spangler, "Organic Syntheses", Collect. Vol. III, Wiley, New York, N.Y., 1955, p 377; *Org. Synth.*, **25**, 42 (1945). Benzoylcoumarins: ref 5b. α-Cyanocinnamamide: ref 5b.

Oxidation of Sterically Hindered Alcohols to Carbonyls with Dimethyl Sulfoxide–Trifluoroacetic Anhydride

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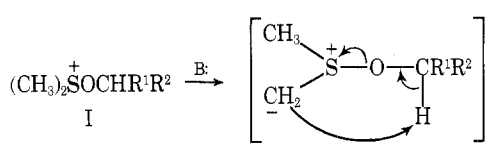
As an outgrowth of our earlier study of a new synthesis of iminosulfuranes,[1] we have investigated a new reagent for the oxidation of alcohols to aldehydes or ketones which appears to be generally useful, operationally simple, highly selective, and efficient.[2] This new reagent, dimethyl sulfoxide–trifluoroacetic anhydride (Me_2SO–TFAA), complements previous reagents[3-13] for the conversion of alcohols to dimethylalkoxysulfonium salt intermediates (I) which, on treatment with base under mild conditions, are rapidly converted to carbonyls in high yields (eq 1):



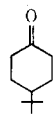
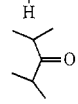
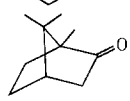
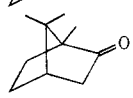
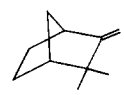
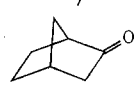
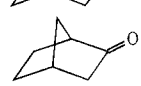
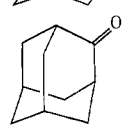
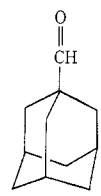
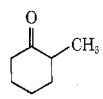
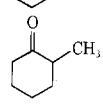
$$\longrightarrow (CH_3)_2S + R^1R^2C{=}O \quad (1)$$

R^1, R^2 = alkyl, aryl, aralkyl, H, alicyclic, etc.

None of the previous methods gives satisfactory results with all classes of primary and secondary alcohols. The new reagent, dimethyl sulfoxide–trifluoroacetic anhydride, now appears to be a most generally useful reagent for the facile conversion of primary and secondary alcohols to carbonyls in high to quantitative yields. In assessing the scope and limitations of this new reagent, the oxidation of some model sterically hindered alcohols was studied. In this note we are reporting the results obtained thus far.

Yields of carbonyls from hindered alcohols (>80–100%) are higher than those from previously studied unhindered alcohols and by-product formation is reduced (usually to <5%) (Table I). We find that (a) the more hindered the alcohol, the higher the yield and alcohols (**5, 6**) with bulky groups on both sides of the carbinol carbon give quantitative yields; (b) no difficulty is experienced in oxidizing primary and secondary

Table I

Alcohol	Carbonyl product	Procedure	Yield, % GLC	Yield, % DNP[a]	Yield, % Isolation
4-*tert*-Butylcyclohexanol (1) (mixture of cis and trans)		C	88	88	
2,2-Dimethyl-1-phenyl-propanyl (2)		A	97	95	
3,3-Dimethyl-2-butanol (3)		C		84	
2,2-Dimethyl-1-propanol (4)		C		81	
2,4-Dimethyl-3-pentanol (5)		C	100	42	86
2,6-Dimethylcyclohexanol (6) (mixture of isomers)		C	100	76	89
1-Borneol (7)		C	98	81	93
dl-Isoborneol (8)		A	93	85	88
8		C	88		
exo-Norborneol (9)		C	95	83	
Norborneol (10) (mixture of exo and endo)		C	96	85	
2-Adamantanol (11)[b]		C	96	95	
1-Adamantanemethanol (12)[c]		C		86	
2-Methylcyclohexanol (13) (mixture of cis and trans)		C	84	80	
trans-2-Methylcyclohexanol (14)		C	80	71	

[a] By isolation of the 2,4-dinitrophenylhydrazone. [b] Added as a solution in Me_2SO (10 ml)–CH_2Cl_2 (10 ml). [c] Additional CH_2Cl_2 (10 ml) was used in the reaction system to effect solution.

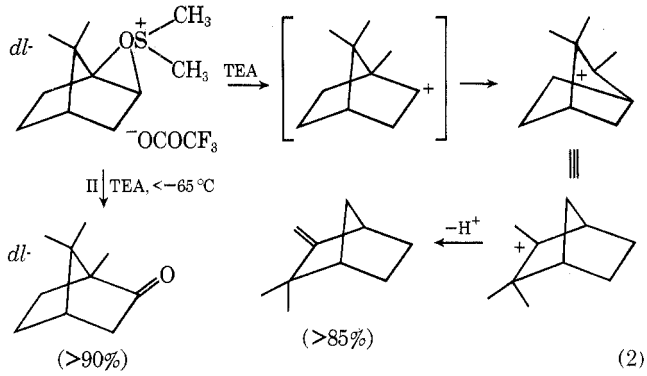
neopentyl-type alcohols (**2, 3, 4, 12**); (c) no substantial difference is noted in oxidizing both exo and endo hydroxyl groups (**7, 8, 9, 10, 13**); and (d) seemingly equally good results are obtained in the oxidation of both equatorial and axial hydroxyl groups (**1, 6, 13**).[1]

The literature is sparse on the oxidation of sterically hindered alcohols with the previously reported oxidizing reagents. Me_2SO–DCC and Me_2SO–SO_3 are reported to oxidize highly hindered hydroxyl groups reluctantly owing to the bulk of the initial adducts and hence are inert, for example, to axial 11β-hydroxyprogestrone.[4] Me_2SO–Ac_2O is often well suited for the oxidation of rather hindered alcohols; however, poor results were obtained in the oxidation of two hindered alcohols, 3,3-dimethyl-2-butanol (**3**)[14] and 2,2,3-trimethyl-2-butanol.[15]

In view of the excellent yields of carbonyls from the hindered alcohols studied thus far, Me_2SO–TFAA is clearly superior to the other reagents and is the reagent of choice for the oxidation of highly hindered alcohols. We believe that this is a consequence both of the smaller size of the Me_2SO–TFAA adduct and the outstanding leaving group property of trifluoroacetate ion.

In addition, the Me_2SO–TFAA reaction occurs instantaneously at very low temperature (<−50 °C) thus making it

possible to oxidize alcohols which form stable sulfonium salts *only* at low temperatures. The oxidation of *dl*-isoborneol is a good illustration of this point. The sulfonium salt (II) is solvolyzed at room temperature (or above) and camphene, the rearrangement–elimination product, is obtained when procedure C (room temperature addition of TEA) is employed. But *dl*-camphor, the anticipated oxidation product, can still be obtained in high yield by addition of TEA at low temperature (<−65 °C). The reaction course is depicted as follows (eq 2):



(2)

Experimental Section

Procedures for Oxidation of Alcohols. Procedure A. To a solution of dry Me_2SO (20 mmol) in distilled dry CH_2Cl_2 (10 ml) cooled below −65 °C with a dry ice–acetone bath, TFAA (15 mmol) in CH_2Cl_2 (5 ml) was added with efficient mechanical stirring in ca. 10 min. After 10 min below −65 °C, a solution of an alcohol (10 mmol) in CH_2Cl_2 (5–10 ml) was added to the mixture in ca. 10 min. The rate of addition of TFAA or alcohol was controlled to keep the temperature below −65 °C. The mixture was stirred below −65 °C for 30 min, followed by addition of TEA (4 ml) dropwise in ca. 10 min. The temperature was maintained below −65 °C until addition of TEA was complete. The cooling bath was then removed and the reaction mixture was allowed to warm up to room temperature (ca. 40 min), then washed with H_2O (20 ml) and the aqueous layer was backwashed with CH_2Cl_2 (5 ml). The combined organic solutions were subjected to GLC analysis as previously reported.[2]

Procedure C. This procedure was identical with procedure A through the addition of alcohol. Stirring was continued for an additional 5 min below −65 °C; the dry ice bath was removed and the stirred mixture was allowed to warm up to room temperature (ca. 40 min). After another 30 min of stirring, at room temperature, TEA (4 ml) was added dropwise (ca. 10 min) at room temperature. The remainder of the workup was the same as in procedure A.

2,4-Dinitrophenylhydrazones.[2] The precipitate was filtered, washed, and dried. Ir and melting point were compared with those of authentic samples.

Isolation of Carbonyls. Ether was added to the reaction mixture which was then washed with dilute HCl, Na_2CO_3, and H_2O in succession. The organic layer was dried over magnesium sulfate and, after evaporation of solvent, a crude product was obtained as a residue. The pure product was isolated either by distillation or short-column chromatography on silical gel with petroleum ether/CH_2Cl_2 as eluent. Physical characteristics (ir, NMR, melting point) were compared with those of authentic samples of carbonyls.

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Registry No.—*cis*-**1**, 937-05-3; *trans*-**1**, 21862-63-5; **2**, 3835-64-1; **3**, 464-07-3; **4**, 75-84-3; **5**, 600-36-2; **6**, 5337-72-4; **7**, 507-70-0; **8**, 24393-70-2; **9**, 497-37-0; *endo*-**10**, 497-36-9; **11**, 700-57-2; **12**, 770-71-8; *cis*-**13**, 7443-70-1; **14**, 7443-52-9; 4-*tert*-butylcyclohexanone DNP, 54532-12-6; 2,2-dimethyl-1-phenyl-1-propanone DNP, 59830-27-2; 3,3-dimethyl-2-butanone DNP, 964-53-4; 2,2-dimethylpropanol DNP, 13608-36-1; 2,4-dimethyl-3-pentanone DNP, 7153-35-7; 2,6-dimethylcyclohexanone DNP, 5074-27-1; 2-bornanone DNP, 2628-66-2; *dl*-2-bornanone DNP, 53567-66-1; camphene, 79-92-5; 2-norbornanone DNP, 3281-03-6; 2-adamantanone DNP, 10535-35-0; 1-adamantanecarboxaldehyde DNP, 18220-81-0; 2-methylcyclohexanone DNP, 5138-30-7.

References and Notes

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Ferrocenecarboxylic Acids from Substituted Ferrocenes. A Convenient and Versatile Oxidation Method[1]

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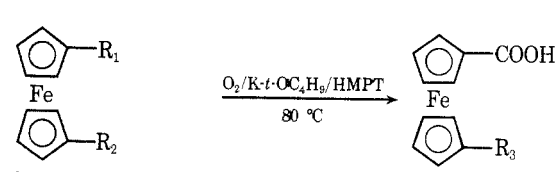
There are only very few examples known in which ferrocenecarboxylic acids can be prepared via side chain oxidation of ferrocenes. The oxidation is limited to ferrocenecarboxaldehydes[2] and acetylferrocenes[3,4] giving only low yields of carboxylic acids.

We now wish to report a convenient and versatile method for the oxidation of hydroxymethyl, formyl, acetyl, and *N,N*-dimethylaminomethyl substituted ferrocenes to ferrocenecarboxylic acids. The oxidation is performed with molecular oxygen at 80 °C in hexamethylphosphoric triamide (HMPT) as a solvent and in the presence of potassium *tert*-butoxide. The results which are summarized in Table I were obtained after a reaction time of 24 h by using 10 equiv of potassium *tert*-butoxide per equivalent of substituent to be oxidized. Lowering the amounts of base gave inferior yields and required longer reaction times.



1a, $R_1 = CH_2OH$; $R_2 = H$
b, $R_1 = CHO$; $R_2 = H$
c, $R_1 = COCH_3$; $R_2 = H$
d, $R_1 = CH_2N(CH_3)_2$; $R_2 = H$
e, $R_1 = R_2 = CH_2OH$
f, $R_1 = R_2 = CHO$
g, $R_1 = R_2 = COCH_3$

2a, $R_3 = H$
b, $R_3 = COOH$

The oxidation reaction with hydroxymethyl, formyl, and acetyl substituted ferrocenes proceeded with almost quantitative conversions. The lower yields of ferrocenecarboxylic acids (**2a,b**) (see Table I) obtained from the oxidation of ac-